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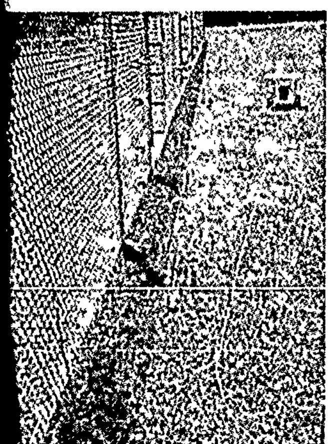
OPERATIONAL PERFORMANCE TESTING OF FENCE-MOUNTED PERIMETER INTRUSION DETECTION SYSTEMS



by

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13. ABSTRACT *(Maximum 200 words)*

Tests and research were conducted at the US Army Engineer Waterways Experiment Station (WES) to determine the feasibility of developing standardized procedures for operational performance testing of fence-mounted Perimeter Intrusion Detection Systems (PIDS). The tests were conducted at the WES PIDS test site using commercially obtained fence disturbance sensors mounted on standard construction perimeter security fences. Methods and devices were investigated in field tests to determine their effectiveness in simulating human intruders and the response of the sensors to these simulated intrusions. Sensor alarm data were collected to quantify the field test results.

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Fence and wire gun	Intrusion alarm loads	Perimeter security
Fence deflections	Mechanical climber	
Fence Protection System (FPS-2)	Pendulum and plate device	

PREFACE

The work reported herein was conducted at the US Army Engineer Waterways Experiment Station (WES), Vicksburg, MS, from February to December 1989 as part of Budget Package 247, Work Unit AT40-DS-001, "Perimeter Intrusion Detection Systems Test and Evaluation."

This study was conducted under the general supervision of Dr. John Harrison, Chief, Environmental Laboratory, (EL), WES, and Dr. Victor E. LaGarde III, Chief, Environmental Systems Division, EL, and under the direct supervision of Mr. Charles Miller, Acting Chief, Battlefield Environment Group (BEG), EL. Planning of the design and conduct of the feasibility study were initiated by Messrs. Miller and Clay Blount, BEG. The field experiments were planned and conducted by Messrs. Blount and Charles R. Malone (BEG). Mr. Blount conducted the data reduction and analysis. Significant contributions were provided by Mr. Lonnie Smith, Instrumentation Services Division, in the design and fabrication of specialized test equipment used in this study. Mr. Matt Hossley assisted in the conduct of the field experiments. The report was prepared by Messrs. Blount, Malone, and Miller.

Commander and Director of WES during this study was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

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TABLE OF CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
inches	2.54	centimetres
pounds (mass)	0.4535924	kilograms

OPERATIONAL PERFORMANCE TESTING OF FENCE-MOUNTED INTRUSION DETECTION SYSTEMS

PART I: INTRODUCTION

Background

1. Over the past 14 years, personnel at the US Army Engineer Waterways Experiment Station (WES) have conducted research and development for the Corps of Engineers concerned with Perimeter Intrusion Detection Systems (PIDS). PIDS are utilized at Department of Defense (DoD) secure-perimeter facilities worldwide fulfilling multiple security roles ranging from anti-terrorism to criminal deterrence. With the proliferation of certain PIDS among the DoD user community has come an increased emphasis on the evaluation of their performance. Accordingly, recent PIDS research has focused on the need to establish a standard set of criteria for acceptance and operational performance testing and evaluation of these systems.

2. Following the installation of a PIDS at a secure facility, acceptance tests are conducted by means of a procedure commonly known as Operational Test and Evaluation (OT&E). If the PIDS has been installed by a private contractor, the OT&E is used to determine if the installation was performed satisfactorily and the PIDS sensor meets the minimum intrusion detection requirements of the site. While most sensors are equipped with self-test processors, OT&E generally consists of visual equipment inspections, standard continuity tests, and performance tests along the secure perimeter. In general, operational performance and acceptance tests consist of simulated intrusions at intervals along the secure perimeter while sensor alarm outputs are monitored. Once a PIDS has been accepted as meeting operational requirements, additional periodic performance and maintenance tests are necessary to insure that the PIDS continues to provide adequate intruder protection. If these tests reveal poor sensor performance or unacceptably high nuisance and false alarm rates, repairs or recalibrations may be necessary. Additional guidance for OT&E is provided in "SAFE Master Installation Acceptance Test and Turnover Plan, SAFE-TP-0023" (US Air Force 1989a).

Problem Statement

3. A recent literature search and a survey of key private and DoD security personnel revealed only limited efforts have been made to develop standard guidelines or methods by which PIDS are evaluated for operational performance and acceptance for installation. While performance criteria are published by PIDS manufacturers, program managers and responsible security personnel at secure facilities are unprepared to adequately test and quantify manufacturer's performance claims. Currently, performance and acceptance tests are being conducted based on manufacturer's guidance and through other techniques which are assumed to be most effective by security personnel at individual sites. This lack of uniformity in testing procedures limits overall confidence in test results from site to site. For example, a sensor system which is subjected to rigorous performance testing at one site may undergo relatively lenient testing at another site, thus defeating efforts to obtain a valid overall perspective of the sensor's capabilities. Additionally, perceived performance capabilities of PIDS sensors at individual sites can be skewed by virtue of the variations in performance demands placed on the sensors by rotating site security personnel. As a result, user feedback on sensor performance capabilities can become contradictory from not only site to site, but also from person to person at the same site.

4. A similar problem that exists regarding current performance testing procedures for operational PIDS is that, in general, operational tests usually consist of human intrusions along the perimeter that generate either "alarm" or "no alarm" results. While this information is useful in an operational sense, it provides very little support for an examination of the sensor's sensitivity variability along the perimeter. In other words, "alarm/no alarm" tests give little indication of the ease or difficulty with which the sensor detects an intrusion from point to point along the sensor line. This means the sensor could be operating well at some locations, but close to failure at others. Without specific sensitivity data, these performance variations most likely remain undetected. As a result, performance flaws and irregular detection patterns with operational sensors, which can compromise the integrity of secure perimeters, can be missed using human intrusion tests.

5. Individual methods are needed for acceptance testing and evaluation of PIDS sensors during installation and for performance and maintenance testing beyond installation. These methods will create a comprehensive uniformity

of evaluation that will insure adequate sensor performance from site to site and from location to location at the same site. Maintenance and long-term monitoring of performance will be simplified by the periodic utilization of these methods. Also, security program managers will benefit from the establishment of test procedures that will eliminate subjective sensor evaluations and create guidelines for sensor acceptance based on site requirements and not necessarily on manufacturer's performance claims and recommendations.

Purpose and Scope

6. In support of the Mandatory Center for Expertise for Intrusion Detection Systems (IDS-MCX), Huntsville Division, Huntsville, AL, WES personnel conducted research efforts and feasibility studies aimed at the development of standardized operational performance and maintenance testing procedures for PIDS. The purpose of this report is to document progress on work which addresses a specific requirement within this broader area of PIDS research, namely the development of performance testing methods for perimeter security fence sensor systems. This report summarizes the efforts of a feasibility study to develop and evaluate methods to realistically simulate a human intruder attempting to scale a standard perimeter fence as well as evaluate fence behavioral characteristics with respect to climbing intruders. In addition, the results of a literature search and PIDS user community survey of methods to simulate fence-cutting intruders are summarized in Part II.

7. The results reported herein will be integrated with similar research efforts conducted recently at the Cold Regions Research and Engineering Laboratory, (CRREL), Hanover, NH. The CRREL work was devoted to developing methods by which a typical perimeter security fence could be instrumented and characterized with respect to several parameters including fabric stiffness, post plumbness, and fence load-deflection factors. The combined result of the WES and CRREL efforts will be the development of standardized methods which can be adopted by the DoD user community to conduct acceptance and long-term performance tests of standard fence PIDS. The results of the CRREL work are detailed in another report (Peck and Walsh 1990).

Feasibility Study Overview

8. The first task in the development of methods to simulate human cutting and climbing intruders was to conduct a survey of the PIDS design, research, development, engineering, manufacturing, and user community. The purpose of this survey was to canvas experts knowledgeable in these fields and draw on their expertise with respect to previously developed methods or devices used for standardized operational testing of fence sensors. This survey revealed that numerous devices and techniques were developed for the testing of intrusion detection capabilities of fence sensor systems, particularly with respect to cutting intrusions. However, few of these methods specifically attempted to simulate the actions of a climbing intruder. This meant that little guidance specifically related to climbing intruder standardized tests was available from the results of previous research efforts. For this reason, the feasibility study focused on climbing intruder standardized test development while the most promising methods of cutting intruder testing methods were evaluated from the results of previously conducted research efforts.

9. As part of the feasibility study, a series of climber tests were conducted from July to November 1989 at the WES PIDS test site in Vicksburg, MS. These tests were conducted to determine the viability of a mechanical fence-climbing device developed by WES engineers. Utilizing design parameters developed in conjunction with IDS-MCX and data supplied by CRREL relating to fence-climbing intruders, the tests were designed to explore the projected operational effectiveness of the device in varied environmental and terrain settings. The mechanical climber was instrumented with a miniature load cell in a way which made the acquisition of sensor alarm load data possible. In addition to these tests, the feasibility study included a series of human climber intrusion tests conducted to compare mechanical and human fence-climber interactions and to explore the relative alarm frequency of each climber type with respect to particular fence sensors. The mechanical and human test series each consisted of a controlled number of climb events at numerous fence locations in order to acquire a significant database for evaluation. These test series are detailed more completely in Appendix A.

10. All human and mechanical climbing data were collected and referenced to prevailing meteorological conditions. The WES PIDS site has a

continuouslv operating meteorological station and the climbing tests were, as much as possible, conducted under similar weather conditions.

PART II: STANDARDIZED PROCEDURES DEVELOPMENT

Design Criteria

11. Standard perimeter security fences are in use at DOD facilities worldwide. While PIDS for these fences exist in many forms, most facilities employ one or more sensors which are attached directly to the fence fabric or superstructure, such as the second generation fence protection system (FPS-2) manufactured by Perimeter Products Inc., Mountain View, CA. FPS-2 utilizes a transducer sensor cable attached to the perimeter fence fabric (Figure 1). This cable extends the length of the fence and is connected to a sensor processor which constantly monitors the sensor cables' frequency output. The FPS-2 generates an alarm when the frequency output of the transducer sensor cable rises to a preset detection level (1.35-1.80 KHz). In other words, when the fabric of the fence experiences a perturbation, whether from a climbing or cutting intruder, an electrical signal is generated between the center conductor and the outer shield of the coaxial sensor cable. The sensor processor analyzes that signal to determine whether it originated from an intruder or from natural phenomena (i.e., rain, wind, snow, hail, etc.). If the processor determines the disturbance is intruder related, an alarm is generated at a sensor monitoring station to alert site security personnel to the intrusion. Since the FPS-2 is widely in use on perimeter security fences, it was chosen as the standard sensor for this feasibility study. Further guidance is provided in a report by Perimeter Products, Inc. (1987).

12. The fences used to conduct this study were two 8-ft* perimeter security fences, approximately 2 and 7 years old, respectively, located at the WES PIDS test site (see Figures 2 and 3). The fences were constructed according to US Air Force specifications outlined in SAFE-SIT-001 (US Air Force 1989b). The fences were constructed of standard 1/8-in. galvanized steel attached to 4-in.-diam fence posts at 10-ft intervals. Horizontal wire stiffeners were fastened at specified intervals along the entire length of the fence near the top and bottom of the fence fabric. Diagonal braces were attached to the fabric at the panels located directly adjacent to the corner and end anchor posts.

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

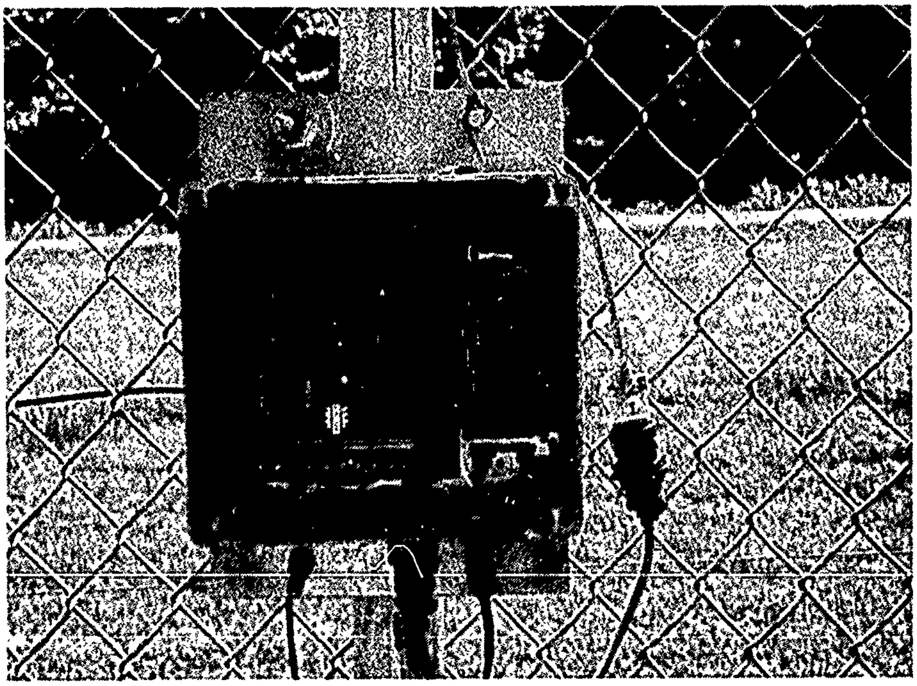

Figure 1. The FPS-2 processor and transducer cable (at left)

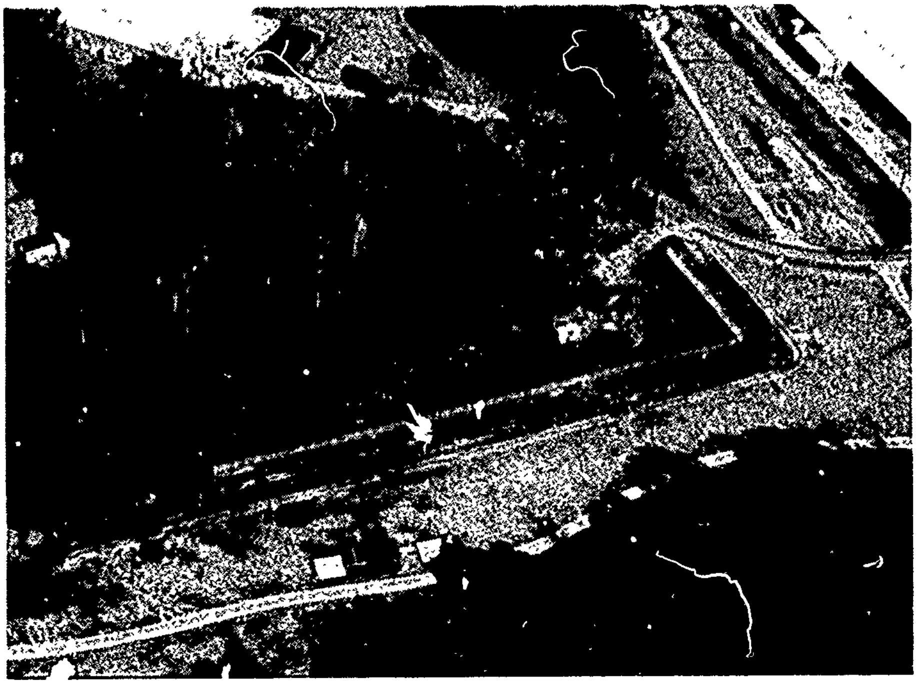

Figure 2. WES PIDS test site

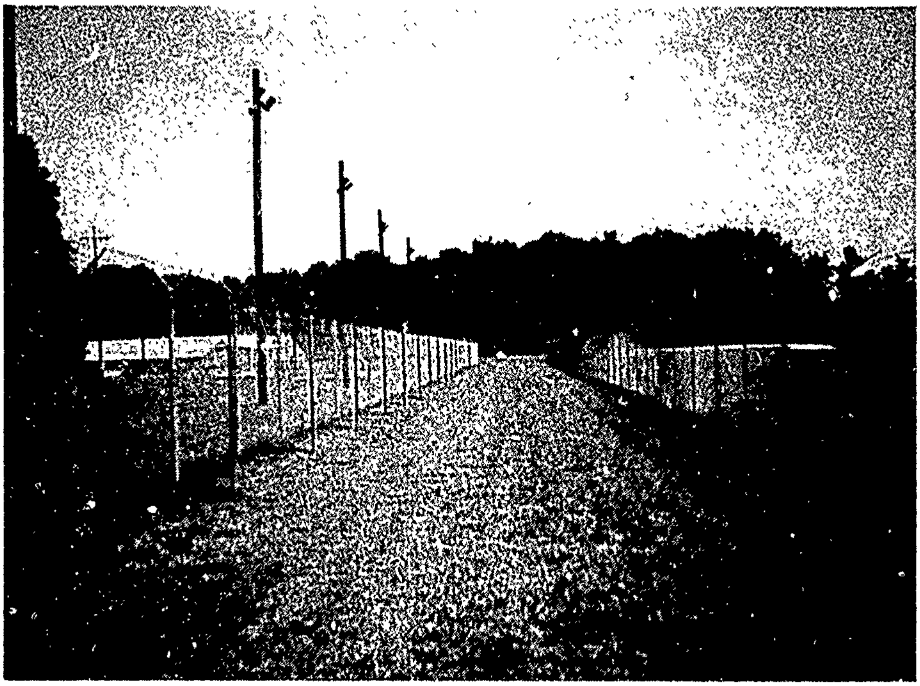

Figure 3. Feasibility study test fences (older (at left) and newer (at right))

13. Choosing the FPS-2 as the test sensor for this feasibility study, WES and IDS-MCX developed criteria to govern the design process of candidate standardized performance testing procedures. The essential design features that shaped proposed methods of performance testing were:

a. Repeatability. An important consideration in the design of performance testing methods was repeatability. A repeatable method was necessary to insure that collective results were compared with confidence and that analyses of these results were based on like test conditions.

b. Quantitative results. An essential feature of candidate testing procedures was that they produce quantitative results. This requirement was necessary for several reasons. First, a quantitative performance test procedure would establish baseline sensor performance results which could be used later for comparison during maintenance and long-term performance tests. If results from operational performance test procedures were indeterminate or inexact, existing sensor performance flaws might go undetected. Second, quantitative results would help to establish a database which, over time, would aid in the prediction of sensor performance under variable environmental conditions. Third, sensor maintenance and troubleshooting would be simplified by the use of a test method that detected sensor performance variations from point to point along a given perimeter sensor line. Finally, if maintenance or performance test methods were not quantitative, long-term deteriorations in sensor performance might go undetected.

c. Field portability. This feasibility study was conducted to address perimeter security fence sensors, so candidate performance test methods or devices had to be portable, since many perimeter security fences are several miles long. A testing method had to be functional for any active portion of the sensor system along the entire length of the perimeter. This requirement meant that the method or device had to be able to operate independently of fixed assets such as electrical outlets and alarm processor stations, and be easily transportable to remote sections of the perimeter.

d. Ease of operation. Since many perimeter security operations personnel do not have scientific backgrounds, any device or method had to be user-friendly, easy to operate, and durable.

e. Cost effectiveness. The cost of a perimeter security sensor could not be overwhelmed by performance testing costs. A mechanical device designed for operational performance testing purposes had to be easy to maintain and repair, and its operation non-labor-intensive. The device also had to have a reasonably long life expectancy.

f. Non-destructive. This feasibility study was initiated to develop standardized performance and acceptance testing methods for operational PIDS. Obviously these methods had to be designed so that the PIDS could remain in place and the perimeter fences would not have to be repaired or replaced as a result of the testing.

g. Human intruder simulation. The design of standardized acceptance and performance testing procedures for perimeter security fence sensors required that a realistic simulation of a typical human intruder be effected. The standard intruder body type selected by IDS-MCX was the fifth percentile Army woman. According to Military Handbook 759A (US Army Missile Command 1981), the fifth percentile woman weighs approximately 103 lb and stands 5 ft tall. Taking these and other physical stature guidelines into account, the WES study attempted to develop a method for human climber simulation that would not only simulate a fifth percentile woman, but also intruders of varying stature if necessary.

Candidate Procedures Selection for Cutting Intruders

14. A literature search and survey of the PIDS user community (Army, Air Force, Sandia Laboratories, and private industry sources) revealed that numerous efforts had been initiated in the past to devise standardized methods of cutting intruder simulation. In fact, several of these efforts had produced viable methods and devices that are generally in use. Realizing that significant time and resources had already been devoted to addressing the subject problem, the decision was made to avoid a redundancy of research and

development efforts and to instead evaluate and select candidate standardized procedures for consideration from among the most promising existing devices and procedures. Two devices that received the strongest endorsements from government and private industry proponents are described below.

15. The fence and wire gun is a pistol-shaped device developed in the 1970's by the US Army. This spring-loaded device is essentially a hollow barrel with a notched flat-headed piston fitted within the barrel. The piston is attached to a finger-operated trigger mechanism and is drawn back by hand from the rear of the barrel to catch in one of the notches near the trigger. By squeezing the trigger, the piston is released from the notch and is spring-driven out the end of the barrel. The flat head of the piston impacts the fabric of the test fence creating a vibrational frequency in the fence fabric similar to that created by a shearing device cutting a single strand of the fabric. If this frequency falls within the detection parameters of the fence sensor, an intrusion alarm is generated. The front end of the barrel is grooved so that when placed directly against the fence fabric, the barrel always remains a uniform distance from the fabric when firing the piston (see Figure 4). The fence and wire gun provides a repeatable testing method assuming the elasticity of the spring and the friction coefficients between the piston and barrel remain constant from test to test. By knowing the spring constant, the coefficients of friction for the piston and barrel, and the distance traveled by the piston, the force imparted by the piston to the fence can be determined for each of the notched firing positions. Also, variable force levels can be imparted to the fence by drawing the piston back to one of

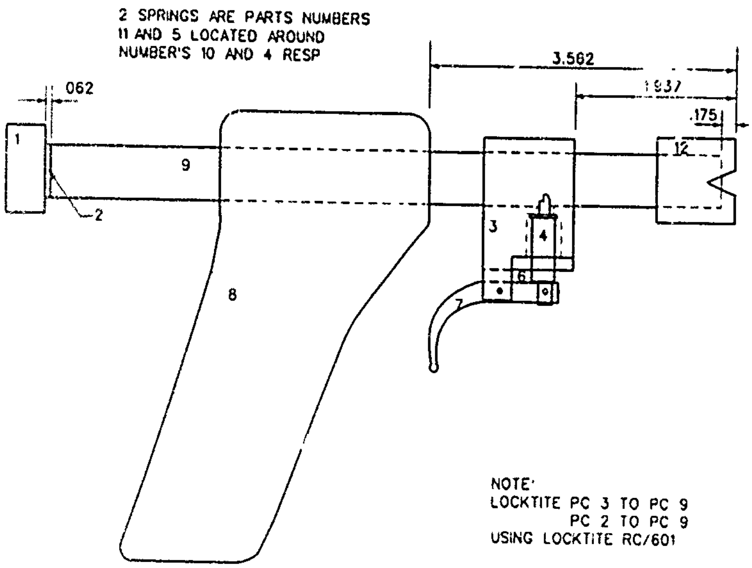

Figure 4. Fence and wire gun schematic

several predetermined distances and holding it there in the respective notches until it is triggered.

16. The second commonly endorsed standardized cutting intruder testing method is a simple pendulum and plate device. (Figure 5 shows a version of a similar device developed several years ago by WES.) A number of government and private sources have independently developed variations of essentially the same product. The basic premise of each of these devices is to use a pendulum or weighted rocker arm attached to the fence fabric to swing downward via gravitational attraction and strike a thin flat-steel plate also attached to the fence fabric. Like the fence and wire gun, the force of the pendulum striking the plate creates a vibrational frequency in the fence fabric similar to that generated by cutting a strand of the fence fabric. The pendulum's weight is known and it is dropped from a predetermined height above the point of impact on the plate. Knowing the arc length traveled by the pendulum to impact the plate and the acceleration of gravity, the force which is imparted to the plate can be determined for any release position.

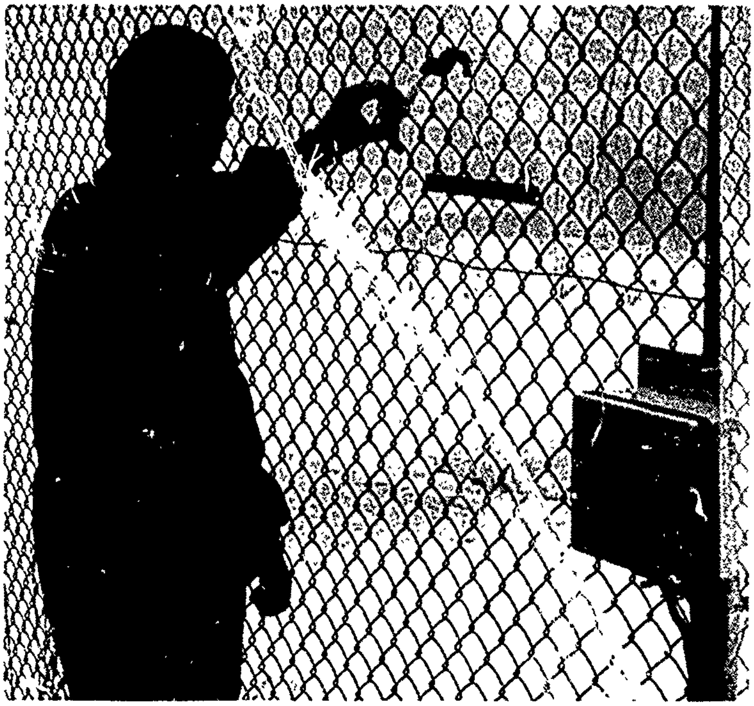

Figure 5. Pendulum and plate device

17. Both of the devices described above meet most of the design criteria established by WES and IDS-MCX. Both are easy to operate, cost-effective, highly portable, and provide calibrated non-destructive testing methods. Each

also provides quantifiable results. However, the pendulum and plate device is recommended as the preferred standardized testing method. The pendulum and plate device has fewer moving parts and does not require the use of a spring to impact the fence. The wire and fence gun, while a good concept, does not remove the potential for human error from the testing procedure. There would be some doubt as to the repeatability of this procedure given that the gun would be hand-held for each measurement. This introduces the possibility that the operator could artificially deflect the fence fabric when positioning the barrel on the fence for firing. Also, the angle at which the piston strikes the fabric relative to the plane of the fence could vary significantly from test to test along the sensor line. The pendulum and plate device, on the other hand, is virtually free from human interference other than at the point of release of the pendulum. Since most devices of this type have an accompanying scaled reference guide denoting recommended pendulum release positions, all the operator has to do is raise the pendulum to one of these positions and let go. Also, the repeatability and variable force level capabilities have been proven from field tests by the Army, Air Force, Sandia Laboratories, and private industry sources. Human error is all but eliminated from this testing method.

18. Since the evaluation of standardized cutting intruder testing methods is not considered to require a formal data collection and analysis program, the remainder of this report will focus on the feasibility study and development of a standardized climbing intruder testing method.

Candidate Procedures Selection for Climbing Intruders

19. The first task in designing a method for simulating a human intruder was to characterize the physical approach of an intruder to climbing a standard perimeter fence. This was done through a series of human climbing tests. During these tests, measurements of intruder hand and foot placements on the fence and fence fabric deflections normal to the plane of the fence fabric were recorded. Videotape of these trials was reviewed and, after some deliberation, a second series of human climber tests were conducted. In the second test series, the FPS-2 processor was activated and alarm events were monitored. Notably, the second test series revealed that the FPS-2 invariably alarmed before the human climbers were able to place two feet on the fences. In other words, when the climbers grabbed the fences with both hands and began

to climb, the FPS-2 alarmed when only one foot was placed on the fence fabric. This fact was critical to the eventual design of a mechanical climber which simulated the interaction between a human climber and the fence fabric.

20. Based on the results of the human climbing trials, several candidate testing methods and concepts were considered for development. Preliminary feasibility tests were conducted to gage the suitability of these concepts to an operational environment. Attention was given to the projected accuracy, ease of use, and versatility of each method as it related to providing a thorough description of the performance capabilities of the fence sensor. Another consideration was that environmental conditions should have no impact on the test method itself; rather, the method would reveal any environmental effects on sensor performance. After evaluating each proposed method with respect to these conditions and the design criteria discussed earlier, a primary candidate for the full feasibility study was selected which met these requirements.

21. The test method chosen for evaluation in the feasibility study was a mechanical climbing device. This device was originally conceived to be constructed somewhat differently than the device which was eventually subjected to a full feasibility study. Several design iterations were carried out during the candidate selection process before the device met the basic requirements necessary to give it full consideration. The next section details the working components of the mechanical climber.

Mechanical Climber Construction and Operation

22. In order to simulate the hand and foot placement of a human climber, a "C"-shaped aluminum rod was fashioned, which attached to the fence in three places (i.e., at two hand positions and one foot position). A crosspiece was welded to the top of the "C" and fitted with hook clamps at each end to function as human hands. These hook clamps attached directly to the fence fabric. At the bottom of the "C", a tennis shoe was fastened to the aluminum rod to simulate a climber's foot (see Figure 6).

23. Human climber trials at WES and CRREL (Figure 7) showed that the weight displacement of a climber was not evenly distributed on a fence between the hands and feet. A climber's lower body was found to be heavier than his or her upper body, thus more force was imparted to the fence through the feet than the hands. Also, a climber's hands pulled the fence fabric outward while

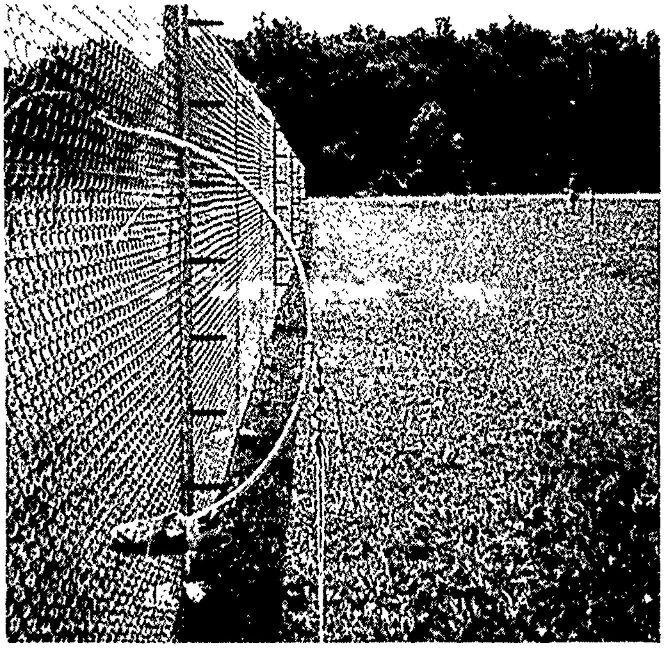

Figure 6. The mechanical climber "C" device

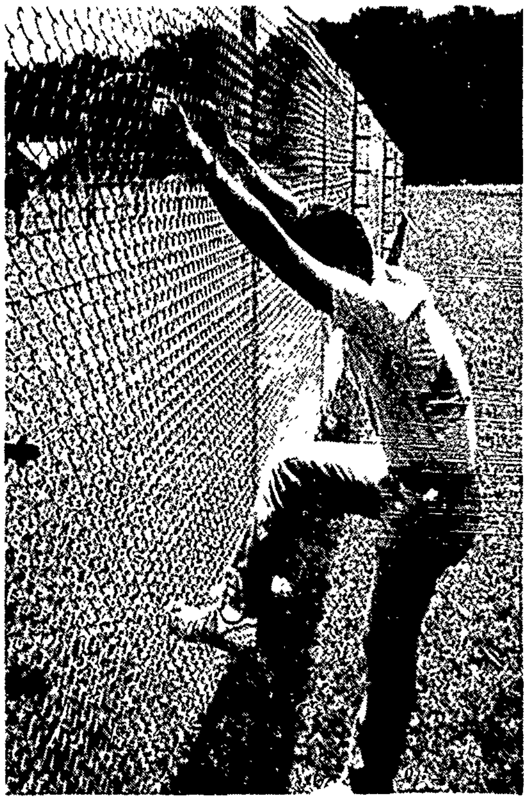

Figure 7. Preliminary human climber trials at the WES PIDS test site

his or her feet pushed the fence down and inward creating a moment about a point between the hands and feet. The "C" device was designed to simulate this moment as well as several possible human weight displacements by means of an eyebolt threaded to the outside edge of the "C." This eyebolt, through which a load was placed on the "C," could be fitted to one of five threaded positions on the outer edge of the "C." A lower eyebolt position would shift the weight distribution higher toward the hand placements, while a higher eyebolt position would shift the weight distribution lower toward the foot placement.

24. To measure loads placed on the "C," a miniature load cell was hung vertically from the eyebolt (Figure 8). The bottom side of the load cell was attached through a pulley system to a small electric winch that was in turn fastened to a thin, steel baseplate situated flat on the ground (Figure 9). The winch was fitted with nylon rope and powered by a 12-v battery. To simulate the load of a climber on the fence, the winch was positioned directly below the "C" in order to pull vertically downward, transferring the downward pull through the "C" to the fence. This downward pull created a force on the fence similar to that of a human climber's weight.

25. As noted above, a miniature load cell was placed in line between the "C" device and the pulley system, which was attached to the winch. The load cell was remotely connected to a digital readout, which displayed pounds of force on the load cell (Figure 10). This reading represented the vertical force imparted to the "C" device at the eyebolt. In order to monitor the performance of the sensor as this force was imparted to the "C" device, the winch was wired directly to the alarm processor of the FPS-2 through a solenoid switch system (Figure 11). When the winch was activated to pull on the "C" device, an alarm was generated by the FPS-2. At the instant of alarm, the electric winch was automatically shut off by the solenoid switch system. At that point, the load cell's digital readout displayed the precise load on the "C" device that had triggered the FPS-2 alarm. In this way, a quantitative measurement of the alarm load was determined.

26. To reduce mechanical noise within the pulley system, the winch aircraft cable was replaced by nylon rope as noted earlier. Also, the hook clamps located on the crosspiece of the "C" device were coated with silicone to further eliminate mechanical noise at the points where the "hands" of the climber attached to the fence. The entire winch and pulley assembly was mounted on a flat 2-ft by 2-ft by 7/8-in. steel plate. This plate was fitted

Figure 8. The miniature load cell attached with an S-hook to the eyebolt

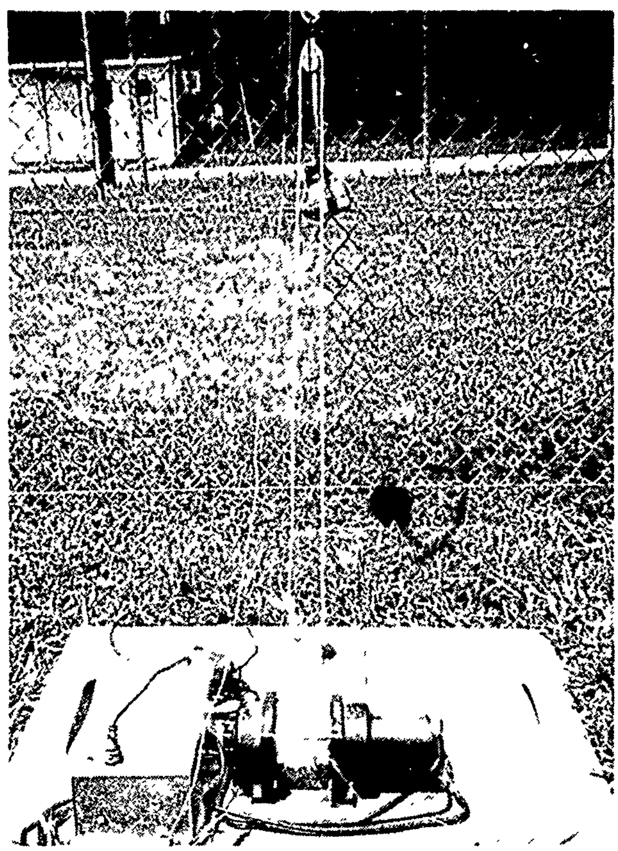

Figure 9. The winch and solenoid switch box attached to baseplate

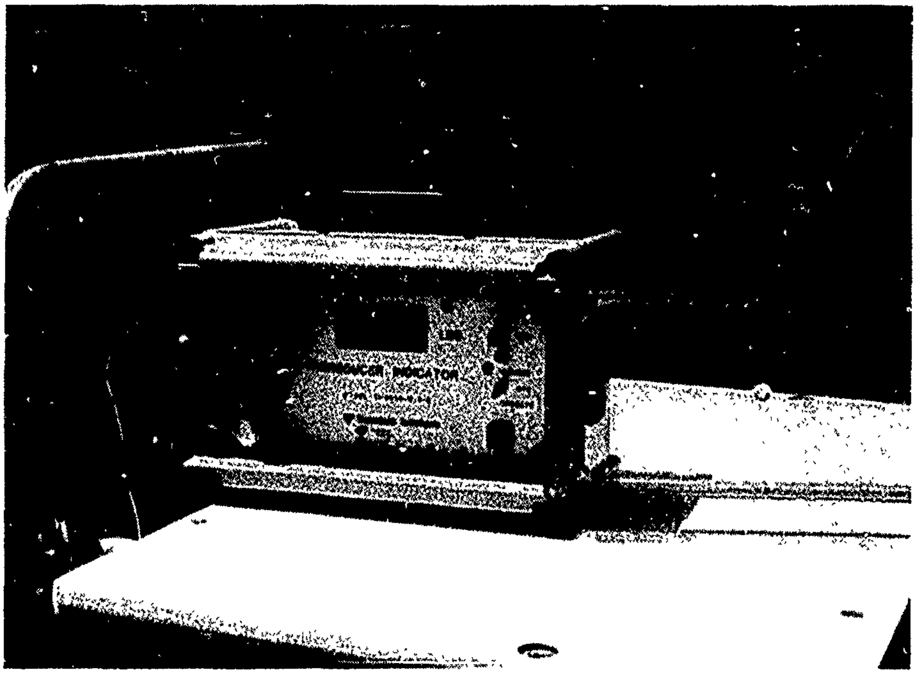

Figure 10. The load cell digital display meter

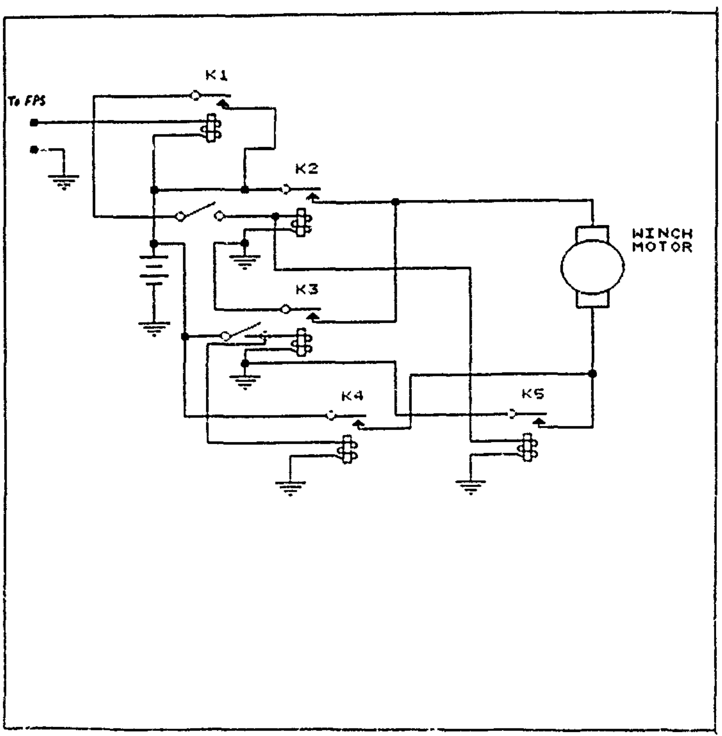

Figure 11. The solenoid switch system wiring diagram for the FPS-2/winch interface

with an axle and wheel system, which allowed for easy transportation to multiple locations along the perimeter.

27. To further fulfill the requirement that the device be portable, a utility cart was crafted to facilitate the transportation of a 12-v battery for the winch (Figure 12). Also, as noted above, the winch was wired directly into the stationary processor for the FPS-2. To facilitate measurements at remote distances from the processor, 100 m of single pair cable were wrapped on a spool and fastened to the utility cart. The winch was powered by a rechargeable 12-v battery, so the system was independent of fixed power sources.

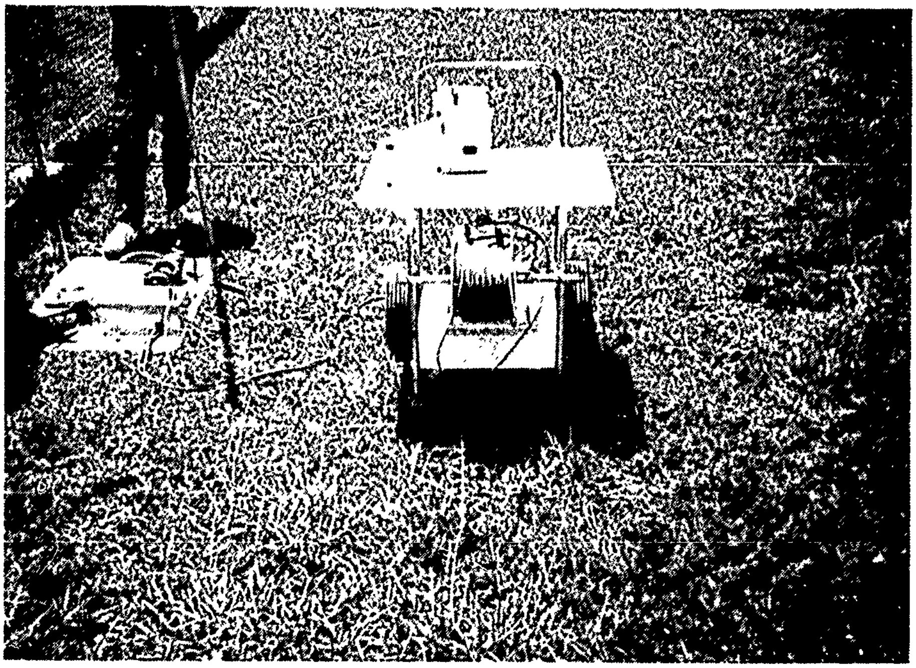

Figure 12. The mechanical climber utility cart

28. Fence deflections at the mechanical climber's hand and foot positions were measured by means of a vertically situated thin aluminum rod and a tape measure. The rod was placed in a position directly opposite the centerline of the "C" and initial distance measurements from the reference rod to the fence fabric were made (Figure 13). When an alarm was generated, a final distance measurement from the reference rod to the fabric was made and the difference between the initial and final measurements represented the fence deflection either into or out of the vertical plane of the fence fabric at the hand and foot locations. A complete test sequence for measuring alarm load

and fence deflection is described in Appendix B and shown in Figures B1-B10. Instrumentation and equipment sources are listed in Appendix C.

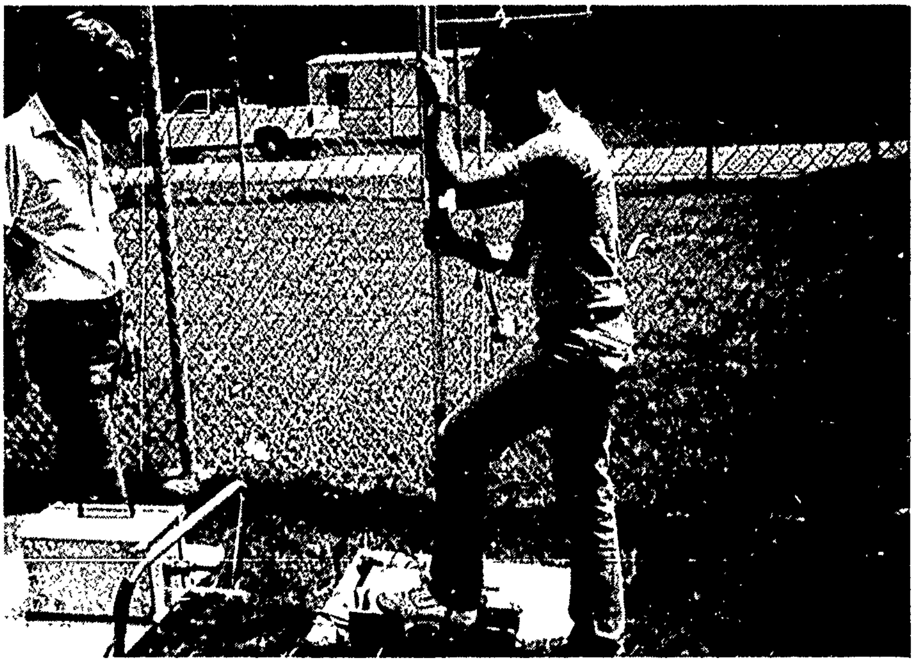

Figure 13. The vertical pole used for fence deflection measurements

PART III: FEASIBILITY STUDY

Mechanical and Human Climber Tests

29. To test the performance of the mechanical climber, a full feasibility study was conducted at the IDS test site at WES. This study consisted of a series of human and mechanical climb events on standard perimeter security fences equipped with the FPS-2 (Figure 14). The purpose of this study was to compare the mechanical climber to human climbers with respect to alarm frequency, fence deflections, and alarm loads. All climb events were conducted under similar environmental test conditions on the same fence sections (see Appendix A: Test Schedule).

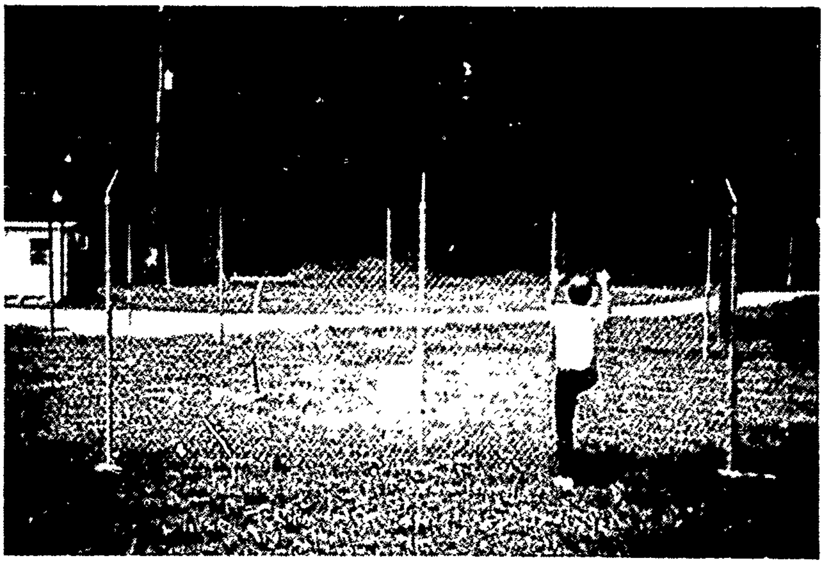

Figure 14. The mechanical climber "C" device compared to a human intruder

30. The feasibility study climbing tests were designed not only to explore the relationship between the human and mechanical climbers, but also to examine other factors including the effect of multiple climb events on the fence fabric, the significance of fence age on sensor performance, and the significance of a climber's position on the fence fabric with respect to alarm generation. Two test locations were chosen for each 10-ft section of fence. At each test location a total of four climbing tests were conducted for both the mechanical and human climbers. The four climb events at each location consisted of an initial climb, an instantly repeated climb, a repeated climb following a 24-hr delay, and a repeated climb following a 7-day delay. This

staggered measurement sequence represented an effort to gage the effect of periodic measurements on the same fence position. These two locations (high and low) were chosen to simulate hand and foot positions typical of taller and shorter human intruders. Identical test measurements were conducted on both the older and newer standard perimeter security fences.

Environmental Considerations

31. The WES PIDS site maintains a 24-hr meteorological station which collects temperature, humidity, solar loading, and other climatic data (Figure 15). A summary of average environmental conditions during the course of the feasibility tests is presented below. While environmental considerations are important to a complete evaluation of the mechanical climber, the prevailing conditions during this study were so similar as to be negligible in differentiating between human and mechanical climber environmental test conditions. Preliminary tests in July were, however, conducted under markedly different environmental conditions. While these tests were uncalibrated, the results were examined with respect to temperature and humidity conditions and no discernible difference in average test results was noticed.

October/November 1989

Temperature (C)	Humidity (%)	Solar Loading (watts/m^2)	Rainfall (in/day)
15.1	72.9	126.73	0.087

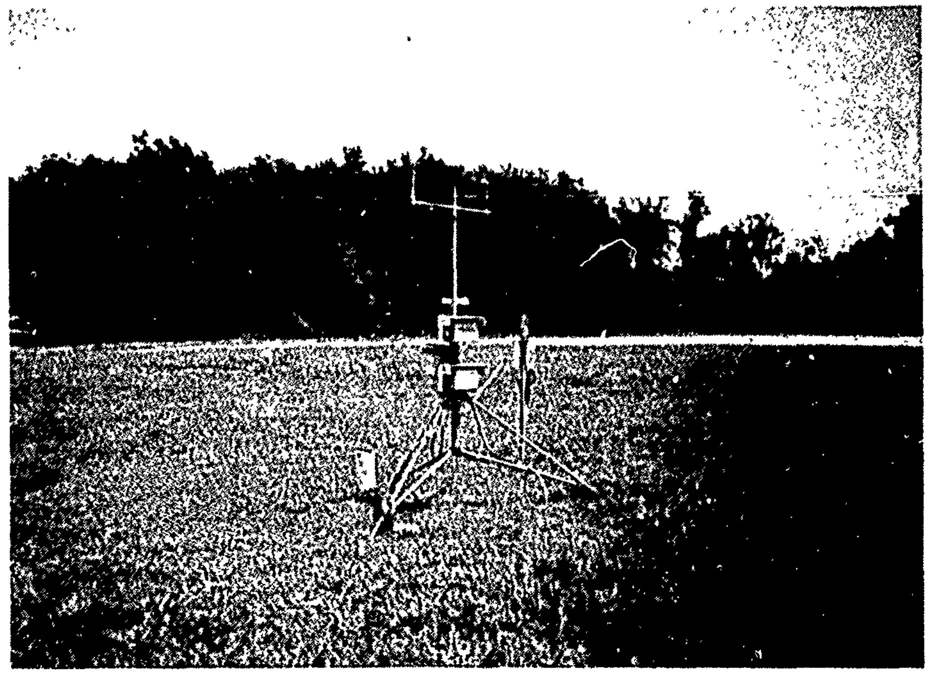

Figure 15. The WES PIDS test site meteorological station

PART IV: TEST RESULTS

32. The results shown in Tables 1-5 represent a summary of results from tests performed on 20 sections each of older and newer fence panels. In each case, the FPS-2 was set to a sensitivity of 5 (1-9 scale) and a pulse count of 1 (1-9 scale). While a pulse count of 1 is lower than a normal operational setting, a count of 1 was used to insure that the FPS-2 would alarm at a point where climber disturbances were first detectable within the alarm criteria of the sensor. Tables 5 and 6 show load distribution breakdowns for the older and newer fences.

33. The fence sensor intruder detection performance during the feasibility study was generally good. Detection rates for climbing tests on the newer perimeter fence approached 98 percent for human climbers and 100 percent for the mechanical climber. Nuisance alarms during these tests were minimal having occurred on average less than once per 3-hr climbing test period. The sensor on the older perimeter fence performed less reliably than the sensor on the newer fence. While both sensors were essentially brand new, the performance of the older fence sensor lagged significantly behind the newer fence sensor particularly with respect to human climber detection rates. The sensor on the older fence was only successful in detecting intruders under 200 lb in approximately 69 percent of the total human climber tests and 75 percent of the mechanical climber tests. This reduced detection capability might have been due to the fact that the older fence fabric was noticeably looser than the newer fence fabric. This is supported by an examination of fence deflection results from the two fences. On average, the older fence deflections were 45 percent higher than the newer fence deflections at the hand positions and 40 percent higher at the foot positions. In addition, human and mechanical alarm loads averaged 70 percent and 112 percent higher, respectively, for the older fence. The variation in detection capabilities and fence deflections could have been attributed to individual sensor performance anomalies, but the sensor processors were exchanged between the two fences following earlier proof-of-principle tests. While the proof-of-principle tests were not conducted under strict test conditions, the trend of higher alarm loads and deflections for the older fence was still apparent even with the sensor processors exchanged between fences. The sensor transducer cables were not exchanged, but following the proof-of-principle tests, a new transducer cable

was installed on the older fence and the trend of higher alarm loads and fence deflections for the older fence continued during the feasibility study tests.

34. The behavior of the two perimeter security fences when subjected to multiple climb events remained fairly consistent. The climber loads required to generate sensor alarms for the same sections of fence showed an average standard deviation of approximately 36 lb for the mechanical climber and 45 lb for human climbers on the newer fence. Alarm loads for the older fence were more scattered with an average standard deviation of approximately 55 lb for the mechanical climber and 20 lb for human climbers. In terms of fence deflections, the results from the newer and older fences were very similar, each showing a standard deviation of approximately 1 in. for all deflection measurements. Tables 5 and 6 show the alarm load distribution of all measurements made. These tables indicate that under similar test conditions, the older fence fabric was more elastic and thus allowed a larger load to be placed on it before a sensor alarm was generated.

35. The mechanical climbing device proved to be easy to operate and capable of functioning with few maintenance requirements even after some 600 climb events during the preliminary tests and feasibility study. The mobility of the mechanical climber was excellent although some design improvements would enhance its ease of relocation. A typical measurement sequence lasted about 3 min per fence location, which was not considered to be unreasonable.

36. The non-destructive design requirement for the mechanical climber was met. The repeatability of results indicated that the fence fabric and superstructure could withstand multiple measurements without deformation even with a relatively short time span between measurements.

PART V: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

37. Based on the results of the study reported herein, the following conclusions may be drawn which support the feasibility of using the WES mechanical climber for standardized acceptance and performance testing of fence-mounted PIDS:

a. The WES mechanical climber meets the design criteria established by IDS-MCX.

b. No method currently exists to quantitatively measure the performance of PIDS fence sensors. The WES mechanical climber has demonstrated the ability to produce quantitative, repeatable results which are similar to the results obtained from human climbing intrusions with respect to alarm frequency, alarm load, and fence deflection.

c The cost of production of the WES mechanical climber is small relative to the cost of a perimeter security fence or fence-mounted PIDS.

d. Fence sensors mounted on older fences may be more vulnerable to undetected intrusions than those on newer fences.

Recommendations

38. Based on the results of this feasibility study, it is recommended that:

a. The WES mechanical climber be integrated with fence characterization techniques developed by CRREL and a database of fence characteristics and alarm load parameters be established. This database should include results from a winter environment test series.

b. A study be conducted to further refine the design of the mechanical climber to best reflect the needs of site security personnel worldwide. This would include soliciting design input from said personnel and incorporating fence characterization guidelines developed by CRREL into a combined standardized performance testing method for fence-mounted sensors.

c. Additional feasibility studies be conducted to address the need for standardized testing methods of other PIDS sensors.

d. The relationship between fence age and PIDS fence sensor performance be more thoroughly examined at other test sites in varied environmental settings.

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Table 1

New Fence Data, Mechanical Climber

Type of Data	Initial Reading Load lb	Initial Reading Upper Deflection in.	Initial Reading Lower Deflection in.	Instant Repeat Load lb	Instant Repeat Upper Deflection in.	Instant Repeat Lower Deflection in.
Average	70.39	2.61	2.19	93.62	3.18	2.63
Standard deviation	36.33	.95	0.80	41.82	1.07	0.91
Variance	1,319.80	.90	0.64	1,749.24	1.14	0.83
Percent standard deviation	51.61	36.37	36.59	44.67	33.60	34.71

Type of Data	24-hr Repeat Load lb	24-hr Repeat Upper Deflection in.	24-hr Repeat Lower Deflection in.	7-Day Repeat Load lb	7-Day Repeat Upper Deflection in.	7-Day Repeat Lower Deflection in.
Average	76.60	2.79	2.29	69.05	2.58	2.19
Standard deviation	35.72	0.99	0.78	33.20	1.20	0.86
Variance	1,275.76	0.99	0.61	1,102.38	1.43	0.74
Percent standard Deviation	46.63	35.71	34.14	48.09	46.32	39.21

Table 2

New Fence Data, Human Climber

Type of Data	Initial Reading	Instant Repeat	24 hour Repeat	7 day Repeat
Average	98.60	123.33	114.83	108.95
Standard deviation	42.58	45.1[illegible]	46.41	46.92
Variance	1,813.19	2,041.22	2,153.64	2,201.20
Percent standard deviation	43.19	36.63	40.42	43.06

Table 3

Old Fence Data, Mechanical Climber

Type of Data	Initial Reading Load lb	Initial Reading Upper Deflection in.	Initial Reading Lower Deflection in.	Instant Repeat Load lb	Instant Repeat Upper Deflection in.	Instant Repeat Lower Deflection in.
Average	152.37	4.61	3.25	151.48	4.71	3.40
Standard deviation	49.50	1.63	1.18	57.20	1.93	1.33
Variance	2,450.33	2.67	1.38	3,271.63	3.74	1.76
Percent standard Deviation	32.49	35.49	36.20	37.76	41.02	39.02

Type of Data	24-hr Repeat Load lb	24-hr Repeat Upper Deflection in.	24-hr Repeat Lower Deflection in.	7-Day Repeat Load lb	7-Day Repeat Upper Deflection in.	7-Day Repeat Lower Deflection in.
Average	149.21	4.60	3.30	149.24	4.30	2.95
Standard deviation	58.09	1.74	1.19	53.49	1.82	1.02
Variance	3,374.12	3.03	1.42	2,861.13	3.30	1.04
Percent standard Deviation	38.93	37.86	36.10	35.84	42.29	34.60

Table 4

Old Fence Data, Human Climber*

Type of Data	Initial Reading	Instant Repeat	24 hour Repeat	7 day Repeat
Average	175.95	180.38	188.45	190.98
Standard deviation	16.10	12.27	27.62	25.27
Variance	259.20	150.48	762.65	638.67
Percent standard deviation	9.15	6.80	14.65	13.23

* All load.

Table 5

Sensor Intruder Detection Rates for Ranges of Climber Loads

Based on All Climb Events - Newer Fence

Climber Type	0-100 lb	101-150 lb	151-200 lb	>200 lb
Human	44.4 %	31.8 %	21.3 %	2.5 %
Mechanical	73.7 %	21.3 %	5.0 %	0.0 %

Table 6

Sensor Intruder Detection Rates for Ranges of Climber Loads

Based on All Climb Events - Older Fence

Climber Type	0-100 lb	101-150 lb	151-200 lb	>200 lb
Human	1.3 %	5.6 %	63.1 %	31.1 %
Mechanical	15.0 %	21.3 %	38.7 %	25.0 %

APPENDIX A: TEST SCHEDULE

1. Mechanical climber intrusion tests were performed by attaching the "C" device at selected fence locations and applying a load as described in Appendix B. When an alarm occurred, the final load readings were recorded as were fence deflections coincident with alarm loads.

2. Human intrusions were performed at fence locations identical to the locations of the mechanical climber intrusions. To effectively determine the human loads that triggered FPS-2 alarms during these tests, an ordinary bathroom scale was used. The human climbers stepped on the scale, which was situated at the foot of the fence. The climber's initial weight was recorded; he then placed both hands on the fence in a natural climbing position. Leaving one foot on the scale, he placed the other foot on the fence and began to climb. At the instant an alarm was triggered, the weight reading on the scale was observed and recorded. The difference between the initial and final scale readings represented the load which triggered the alarm. This method was consistent with earlier observations that revealed the FPS-2 generated an alarm prior to the climber's ability to place two feet on the fence. In order to know the moment the FPS-2 generated an alarm during these tests, an audible alarm generator was connected to the alarm output of the FPS-2 processor (Figure A1).

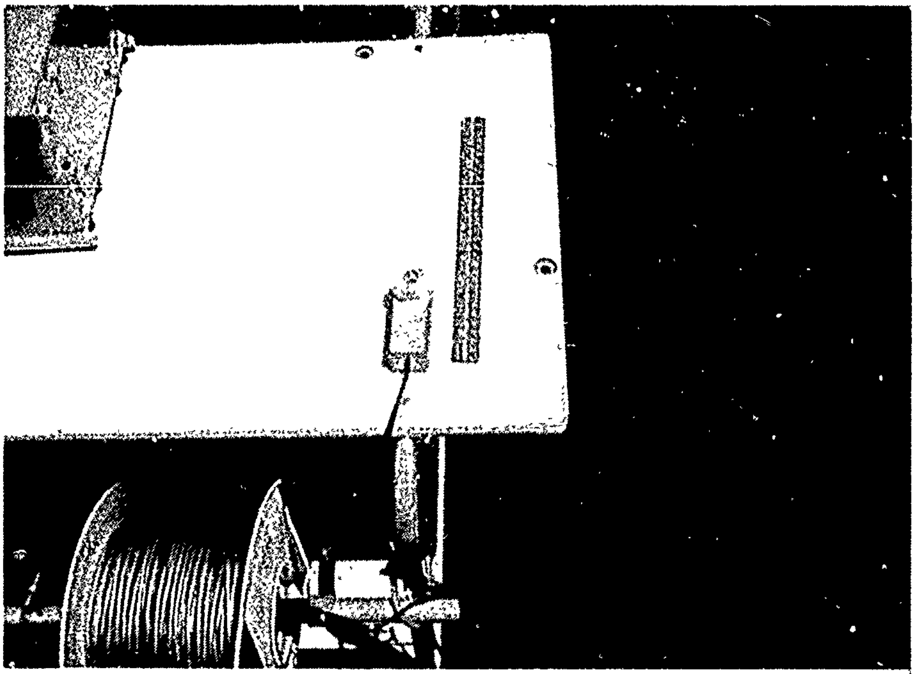

Figure A1. The audible alarm used for intruder detection alarm generation during human climber tests

APPENDIX B: MECHANICAL CLIMBER TEST SEQUENCE DESCRIPTION

1. The mechanical climber may be operated effectively by two people. The only requirement is that they each weigh at least 100 lb. The mechanical climber requires no external power source other than the 12-v battery that is part of the ancillary equipment. Figures B1-B10 illustrate the steps to operating the mechanical climber, which are described below.

2. The first step in making operational performance test measurements with the mechanical climber is to hook the winch-processor single pair cable into the plug, which is connected to the alarm output of the processor of the fence sensor to be tested (Figure B1), in this case the FPS-2 fence protection system. After the winch-processor cable is connected, the climber utility cart and baseplate are wheeled to the first fence test position. The cart must be placed in close proximity to the fence test location (i.e., within 10 ft of the fence fabric) (Figure B2).

3. The next step is to attach the mechanical climber "C" device to the fence fabric. This is done by simply fastening the two hook clamps on the "C" crosspiece at the desired "hand" locations on the fence fabric (Figure B3). For optimum results, the hooks should be fastened at approximately the same height on the fabric. Once the hook clamps are attached, the shoe at the bottom of the "C" is fitted into one of the diamond-shaped openings in the fence fabric. (Note: The "C" device is designed so that the shoe falls naturally into a diamond-shaped fence opening with little or no manipulation. The spacing between the "hands" and the "foot" of the "C" device represents an average spacing derived from human climber tests of several climbers of varying heights.)

4. Once the "C" device is in place, the load cell is connected to the digital display located on the utility cart via the load cell output cable (Figure B4). The miniature load cell and pulley assembly are then hung from the eyebolt located on the outer edge of the "C" device (Figure B5). The digital display is turned on and allowed to warm up for approximately 1 min prior to beginning a measurement series. The digital display should then be calibrated to read zero or no load before making the first measurement.

5. The next step is to connect the winch-processor coaxial cable that runs from the alarm processor through the cable spool and into the winch solenoid control box. This is done by plugging the cable into a jack located on the outer surface of the winch control box (Figure B6). The winch power

Figure B1. The winch-processor cable is plugged into the FPS-2 alarm output

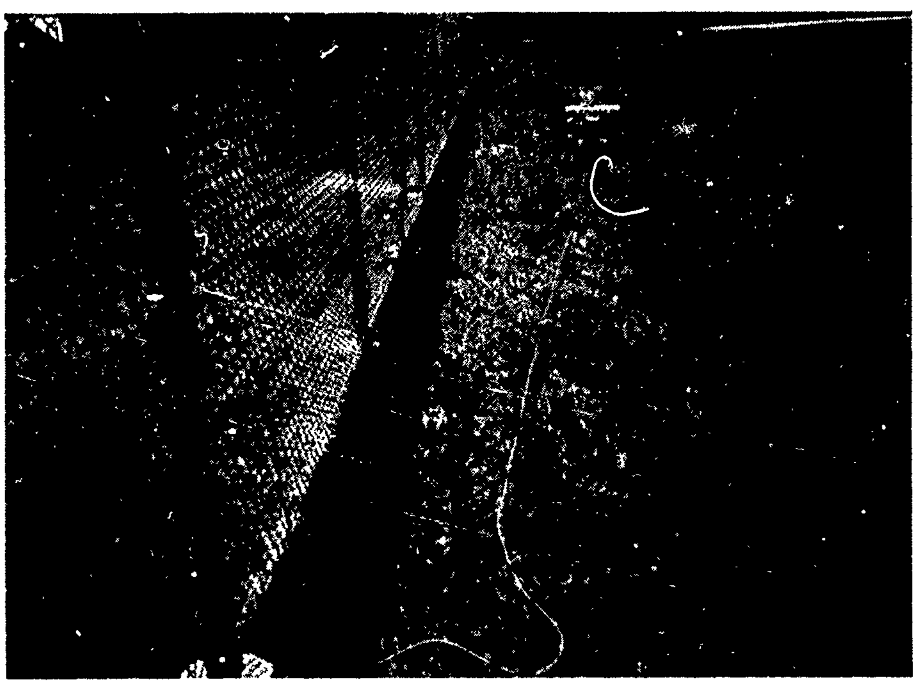

Figure B2. The mechanical climber utility cart is wheeled to the first fence test location. (Note winch-processor cable in the foreground)

Figure B3. The mechanical climber "C" device is fastened to the fence fabric at the first test location

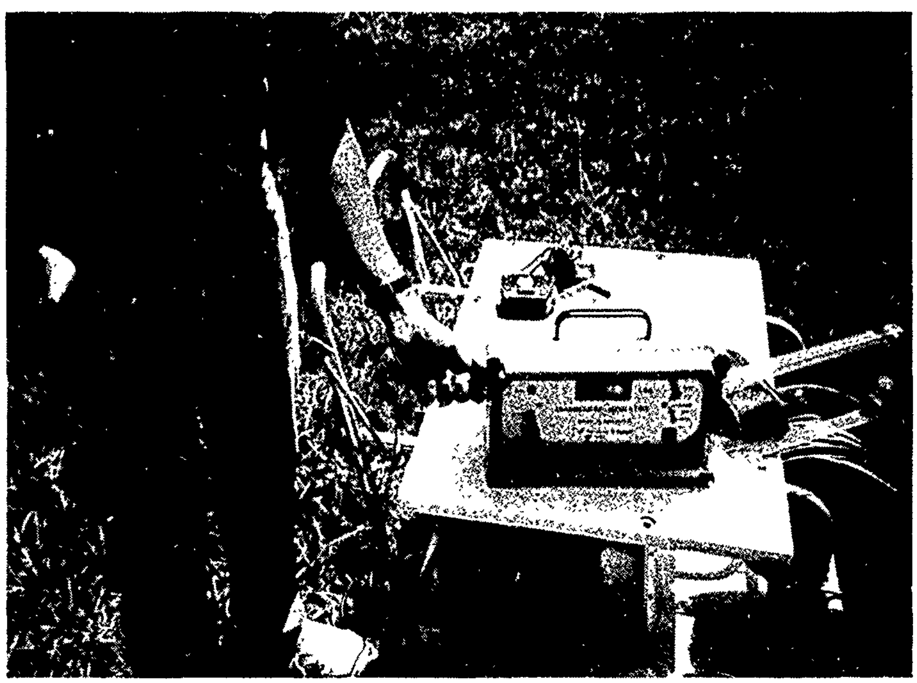

Figure B4. The miniature load cell output cable is plugged into the digital display load cell meter

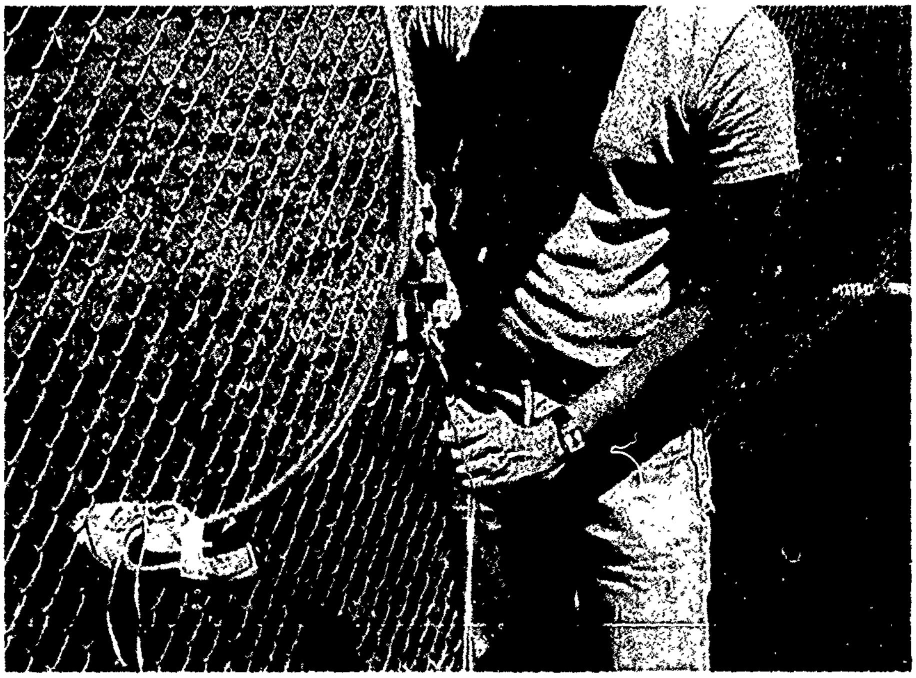

Figure B5. The load cell and pulley assembly are hung from the eyebolt on the outer edge of the "C" device

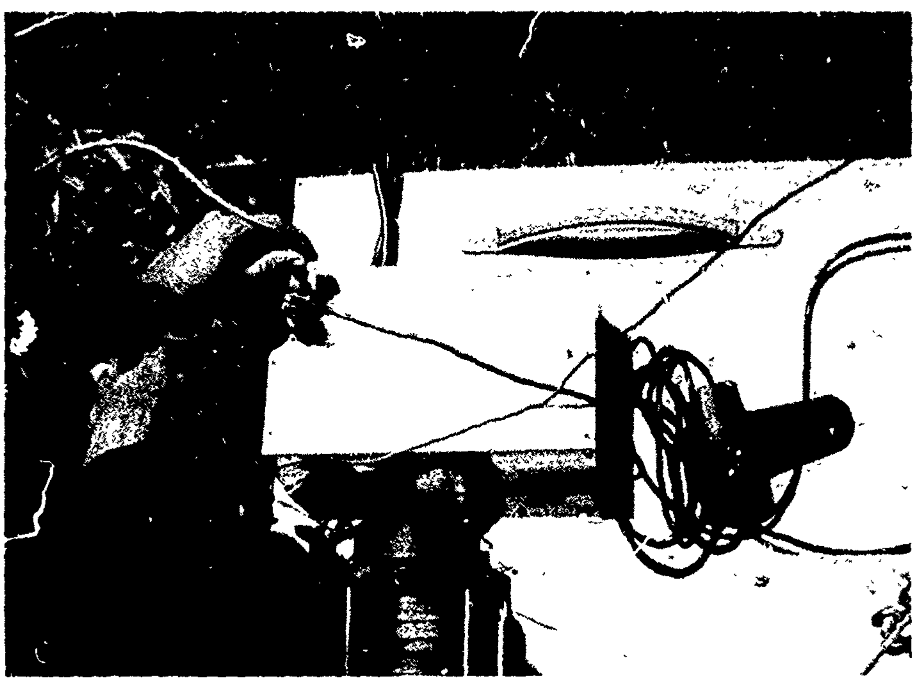

Figure B6. The winch-processor cable is plugged into the winch solenoid control box cables are then attached to the positive and negative posts of the 12-v battery located on the utility cart.

6. The mechanical climber is now ready to operate. Prior to beginning a measurement, a vertical pole is erected directly opposite the "C" device. This aluminum pole is fitted with a 6-in. sharpened spike and a foot peg on the bottom and can be easily driven into the ground with one foot. Using a tape measure, the horizontal distance from the pole to the fence fabric at the "hand" and "foot" locations is measured (Figure B7). Both operators then stand opposite each other on the flat plate that serves as the base for the winch (Figure B8). This prevents the plate and winch assembly from lifting off the ground when the winch is activated. The combined weight of the two operators should equal at least 200 lb since the load cell is capable of measuring a load up to that weight (200 lb was chosen as a maximum weight since it was reasoned that if a fence sensor was incapable of detecting a 200-lb intruder, the sensor was malfunctioning or the condition of the fence had deteriorated to an unacceptable state.) Using the hand-operated control, the winch is activated. At some load value from 0 to 200 lb, the fence sensor generates an alarm and the winch shuts off automatically. Using a tape measure, the fence deflection at alarm is determined by again measuring the distance between the vertical pole and the "hand" and "foot" locations on the fence fabric. The alarm load is then read directly from the load cell digital display (Figure B9). Deflection and load measurements are recorded and the measurement sequence is complete. The hand-operated winch control is then used to reverse the winch motor and the load is removed from the "C" device and the fence. The "C" device is detached from the fence fabric and the mechanical climber can then be rolled to a new fence location to begin another measurement sequence (Figure B10). (Note: The wheel and axle assembly attached to the steel baseplate described in Part II was a feature added after the feasibility study was completed.) A complete measurement sequence takes approximately 3 min per location.

Figure B7. Initial or zero deflection measurements are made prior to the activation of the winch

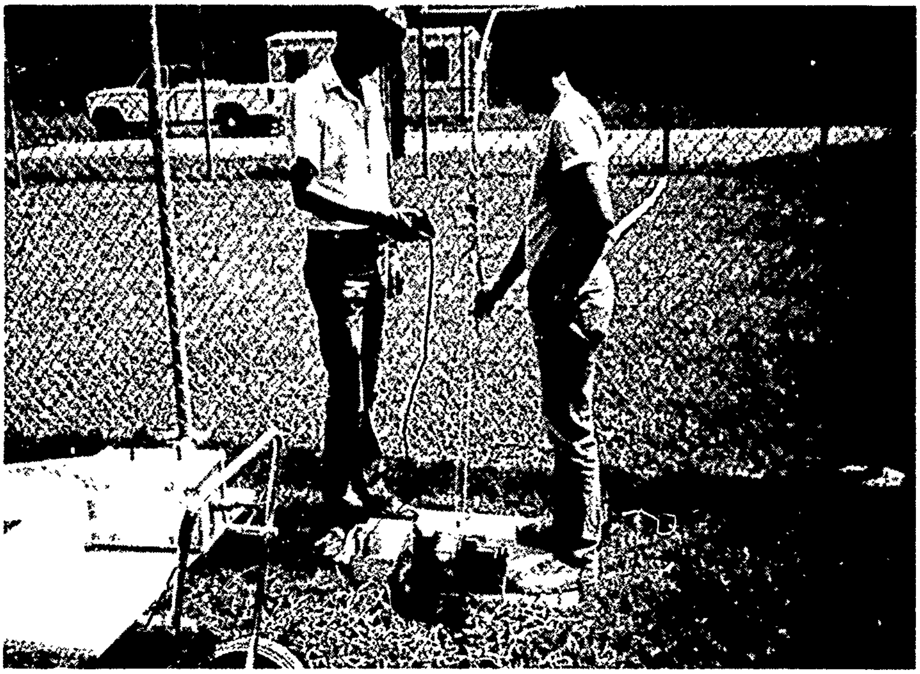

Figure B8. A load is placed on the fence by activating the winch with the winch control trigger

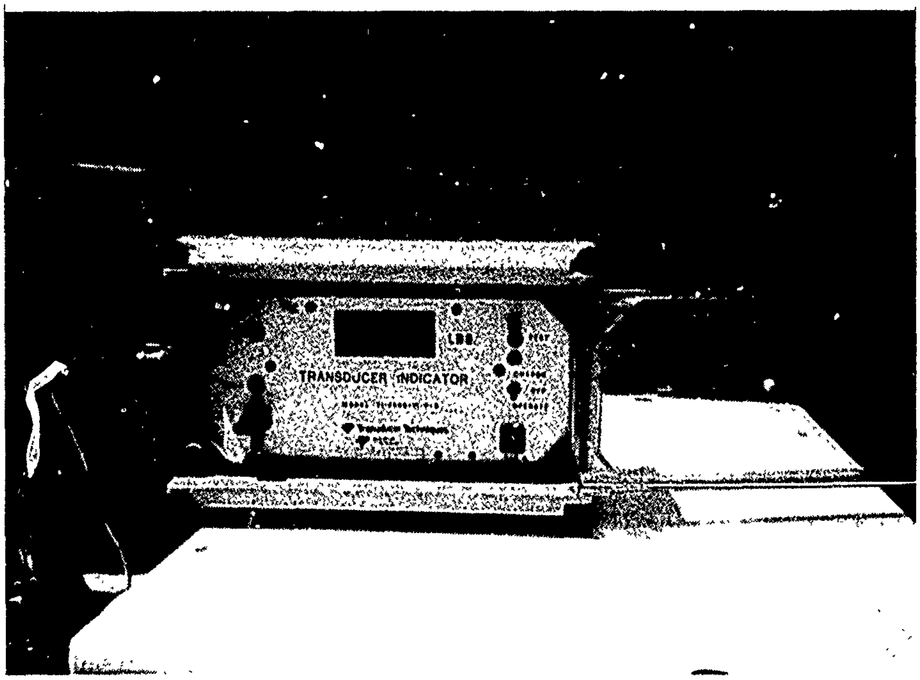

Figure B9. The load cell meter displays the load on the fence at the moment an alarm is generated

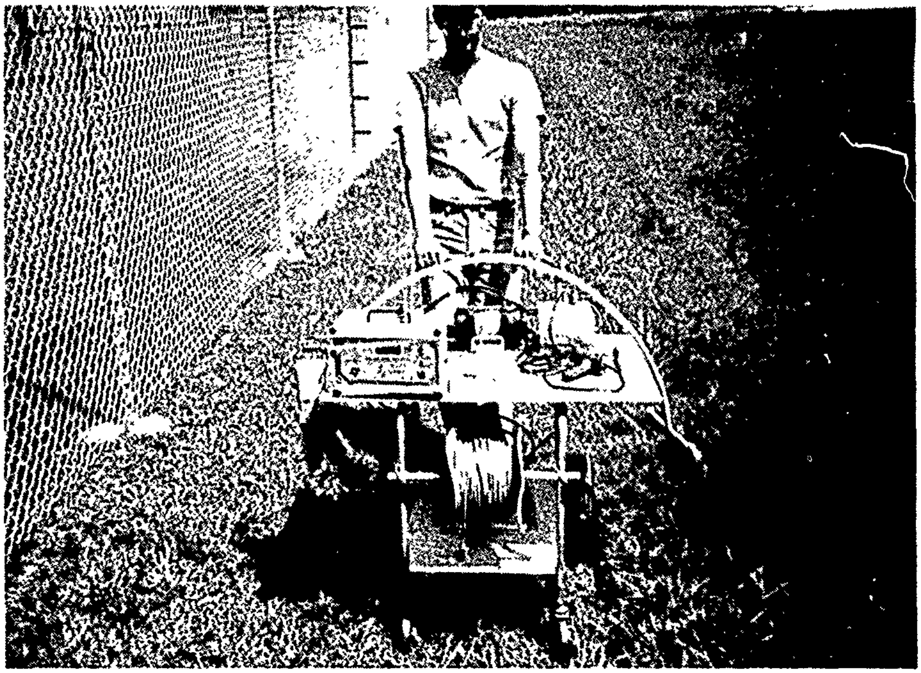

Figure B10. The utility cart is wheeled to the next test location

APPENDIX C: INSTRUMENTATION AND EQUIPMENT

1. This feasibility study was conducted using primarily off-the-shelf instrumentation and equipment. Some components of the mechanical climber were constructed by the Engineering and Construction Services Division of the US Army Engineer Waterways Experiment Station. All other components of the mechanical climber were obtained through commercial sources.

Load cell	Model# TI-2000-WP-3.5-BAT, Transducer Techniques, 43178 Business Park Drive B-101, Rancho California, CA 92390.
Load cell meter	Model 2840A, Transducer Techniques, 43178 Business Park Drive B-101, Rancho California, CA 92390.
Winch	Model# U2000CL, Warn Industries Inc., 13270 S.E. Pheasant Court, Milwaukie, OR 97222.
Fence sensor	Fence Protection System, FPS-2, Perimeter Products, Inc., P.O. Box 1448, Mountain View, CA 94042.
Audible alarm	Sonalert, Model# SC1.5, Mallory, Inc., purchased through Newark Electronics, Inc., 6045 Ridgewood Rd., Jackson, MS 39211.